OCCUPANT INTERACTION WITH VENTILATION SYSTEMS

7th AIC Conference, Stratford-upon-Avon, UK
29 September - 2 October 1986

PAPER S.1

VENTILATION AND ENERGY EFFICIENCY - Keynote Address

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Introduction

1. The Energy Efficiency Office provides the United Kingdom's subscription to the Air Infiltration and Ventilation Centre. This is appropriate since improved energy efficiency must be a principal goal of air infiltration studies. Through better understanding of infiltration rates and occupants' needs, we are able to design and construct buildings which provide adequate but not excessive ventilation for their occupants, and can thus minimise the energy demand arising from ventilation requirements.

2. In this address, therefore, I wish:

a) to set an energy efficiency context for research into air infiltration;

b) to summarise current research themes;

and c) to suggest aims for research in air infiltration and occupant behaviour.

I hope that this will provide Conference participants with a suitable framework in which to place subsequent papers.

Energy Use and the Energy Efficiency Office

3. In 1984, the United Kingdom used 8161 PJ of primary energy while consumption by final users amounted to 5682 PJ (Reference 1). Table 1 shows how final and primary energy uses were distributed among different sectors of the UK economy; a similar pattern may be observed in most European countries. In the USA and Canada, though, the transport sector accounts for a rather higher proportion of final energy use.

4. It is clear that energy uses in buildings account for a large proportion of the UK's energy consumption. All consumption in the 'domestic' and 'commercial/institutional' sectors and some in the 'industry' sector can be attributed to buildings. In primary energy terms, buildings account for approximately one half of the national total; in final use terms, the proportion is somewhat less because of the smaller conversion losses in industry and the transport sector, a reflection of the lower use of electricity in these sectors.

5. Space heating is the dominant energy use in most classes of building. Taking major sectors, Table 2 shows the distribution of energy use in the domestic sector and Table 3 the distribution in commercial and institutional buildings, both in primary energy terms (Reference 2). Energy savings in space heating may be made though improvements to fabric insulation, glazing, heating and control systems and through reduction of infiltration. The relative importance of each will vary widely according to the type, size and construction of the building.

6. Over the UK economy, savings of at least 20%, worth £7 billion per annum, are possible through measures that will pay for themselves in timescales acceptable to the energy consumers concerned. In industry, this in general means pay-back periods of less than two years. For

buildings, longer pay-back periods - perhaps up to 7-8 years - are accepted. The Energy Efficiency Office was created within the Department of Energy in 1983 to devise and administer programmes that would alert all energy users to the potential for cutting their energy costs and would help to achieve greater efficiency in energy use. Through these programmes, the EEO aims to strengthen the underlying trend towards improved energy efficiency in the UK economy and to secure this 20% improvement by the mid-1990's.

7. The annual budget of the Energy Efficiency Office is about £25million. Its principal programmes

(i) advertising and advice aimed at all energy use sectors, but particularly domestic consumers;

(ii) breakfast-time seminars for executives in both public and private sectors, addressed by Ministers (16000 executives attended the first series);

(iii) grants towards the cost of energy surveys in industry and non-domestic buildings;

(iv) grants towards the installation of novel technology for improving energy efficiency, independent monitoring of performance in use and vigorous promotion of the results if successful;

(v) development of improved management techniques for energy use in industry and commerce;

(vi) improvement of energy efficiency in Government and other public sector buildings;

(vii) insulation and draught-stripping of homes of low-income householders.

8. Underpinning these activities is an R & D programme which covers a wide range of studies from the co-funding with firms of new technological developments to evaluating the relative effectiveness of different approaches to the promotion of energy efficiency. The Office's support for the AIVC comes from this programme.

Ventilation and Energy Use

9. In recent years, stimulated initially by the sharp rise in energy prices in the early 1970's, insulation standards in new buildings have risen substantially. This change, however, increases the relative contribution of ventilation losses to total space heating requirements. Table 4 shows how fabric and ventilation losses changed in a typical UK semi-detached house between 1970, when no thermal insulation standards were included in Building Regulations, and 1980, when Regulations set maximum 'U' values of 1.0 W/m^2K for walls and 0.6 W/m^2K for roofs. The Table also gives a possible future figure, for a time when maximum U-values might be around 0.3 W/m^2K. It is clear that control of infiltration becomes increasingly important.

10. These average figures disguise another effect which makes ventilation losses even more important in relation to comfort - the variation with wind direction. As ventilation losses become a larger component of total demand, rapid variations in room ventilation rate as the wind changes direction, with consequent variations in the heating load, mean that the heating system must be properly sized and controlled to be able to respond. Figure 1 illustrates this effect.

11. Calculations such as those on which Table 4 is based always have to assume an average 'whole house' ventilation rate. One air change per hour (1ach) is often chosen, because it represents adequate but not excessive ventilation. The actual ventilation rates experienced in real houses, however, vary considerably. Tracer gas techniques provide direct measurements of ventilation rates. However, they are time consuming and expensive, and in the UK relatively few measurements - mainly of whole house infiltration rates - have been made. Figure 2 gives the distribution of whole house infiltration rates for 430 measurements in a sample of 26 houses (Reference 3); the mean is 0.7ach and the tail of the distribution extends just beyond 2ach.

12. Fan pressurisation is much simpler, and although this gives information on the air leakage characteristics of a building rather than the air infiltration rate, calibration through tracer gas studies does allow the infiltration rate to be estimated with reasonable accuracy. In particular, the leakage rate at 50Pa applied pressure can be a good indicator of whether natural infiltration is normally inadequate, excessive or satisfactory. Figure 3 shows the distribution of leakage rates at 50Pa in a sample of 100 UK dwellings (Reference 4); generally acceptable values lie in the range of 10-20ach (with doors and windows closed, and flues sealed).

13. These recent measurements by the Building Research Establishment and others indicate that the spread of infiltration rates in the UK housing stock is considerably narrower than was previously considered likely, with far fewer dwellings now expected to have highly excessive ventilation rates. Nationally, perhaps some 30-40% of the present stock could benefit from reduced infiltration rates, The current BRE view is that the majority would be limited to a reduction of no more than 0.5ach on safety and other grounds. The national annual primary energy savings would be about 40 PJ.

14. Thus the energy savings to be obtained through reduced infiltration in UK housing are equivalent to some 2% of domestic energy consumption or 4% of domestic space heating consumption, and are worth over £100 million annually. Savings in non-domestic buildings are probably in the £50-100 million range, but there is little information on which to base an estimate.

Constraints on ventilation control

15. Control of infiltration can thus make a significant contribution to improved energy efficiency. However, in providing advice on how to reduce infiltration rates, or attempting to specify rates in Regulations, official bodies such as the Energy Efficiency Office face a number of problems.

16. First, there is, in the UK at any rate, considerable uncertainty about the minimum ventilation rate required for safety and comfort. If ventilation is inadequate, the water vapour produced in the course of domestic activities will remain in the dwelling and will eventually condense on cold surfaces, with resulting problems of mould and damage to the fabric. The other pollutants produced by human activities and by furnishings - tobacco smoke, formaldehyde, combustion products etc - also have to be removed and the need to control radon originating in the ground has recently been identified as an important factor in some areas of the UK. In general, however, the dominant pollutant is water vapour. The UK climate is characterised by high relative humidity and many houses show signs of condensation problems - Table 5 shows the results of one survey of English houses. In order to avoid such problems, BRE recommend a whole house ventilation rate of around 0.7ach, with specific recommendations for rooms with moisture generating activities, eg bathrooms, and other special circumstances.

17. Secondly, even if one could specify precisely the required average ventilation rate, there are no simple methods for deciding upon the measures that should be adopted in order to achieve this rate. Mechanical ventilation, combined with heat recovery and a very tight construction, is one option. This is rarely used at present in the UK because of its cost, and most dwellings will for the foreseeable future depend upon natural ventilation and infiltration. The infiltration rate in new buildings will depend upon factors such as the form of construction, the quality of workmanship, internal layout and the exposure of the site. Moreover, it will tend to increase in the first year or two owing to settlement, drying out etc. In existing buildings, only general guidance on the measures to be adopted can be given since the rates for air infiltration will not be known in detail. Moreover, until recently, there was very little objective information available on the performance of even common means of reducing infiltration e.g. the various methods of draught-proofing doors and windows. As a result of recent BRE research, some funded by the EEO, it is now possible to specify the most appropriate material for different situations. This is, however, by no means the complete answer to the problem of specifying measures appropriate to a particular building.

18. Thirdly, there is a lack of convenient testing procedure which can identify infiltration routes and enable builders to check whether targets or mandatory requirements have been met. Ideally, tracer gas techniques would provide the most accurate measurement of air infiltration rates. However, the time and expense involved makes this approach quite unsuitable. Pressure testing has become a recognised proxy technique. Whole-house pressurisation is specified in building standards in Norway and Sweden, and in draft standards in North America, where builders use it for quality control and developers find it a useful selling point. Furthermore, most industrial countries have pressurisation standards for building components such as windows. In the UK, BRE has produced a protocol on pressure testing drawing upon overseas experience as well as that of BRE and the very limited number of other UK practitioners. At present, since the Building Regulations contain no specific infiltration requirements, this protocol is used mainly as a guide for UK ventilation research groups. The routine use of test procedures by housebuilders is some way off.

19. Finally, even if rates could be specified, achieved in practice and checked, there would remain the influence of the building's occupants - which is the theme for this conference. If, for whatever reason, they decide that the ventilation provided is inappropriate, they will open windows or stop up ventilators. Custom and practice, just as much as reactions to the local environment, will I suspect have a large influence here. You will, though, be considering this over the next three days and I shall not say more now.

20. The conclusion I draw from this is that at the moment it is not realistic to include requirements on ventilation rates in UK Building Regulations. They could not be specified with sufficient confidence, nor could conformance be monitored. However, non-statutory documents should certainly include guidance on the control of infiltration. Thus the advisory material available from bodies such as the EEO covers the principal ways in which householders can reduce draughts. And professional codes, such as those of the British Standards Institution, can promote good practice in control of infiltration.

Current Research

21. Funding for UK research relevant to the control of infiltration comes in general from public sector sources, primarily the Department of the Environment, the Energy Efficiency Office, the Science and Engineering Research Council and the public sector fuel industries. Research is in progress at the Building Research Establishment, the research establishments of the Electricity Council and British Gas, the Building Services Research and Information Association (BSRIA) and a number of university and private sector laboratories.

22. Research is aimed at the four main problem areas outlined above. First, how can one establish appropriate ventilation rates? BRE is studying the incidence of condensation problems and measures for countering them, including extra ventilation, fungicides and dehumidifiers. Another programme is studying mould growth in timber and the effects of wood preservative while the main ventilation research section at BRE is studying indoor air quality requirements and standards.

23. Secondly, how can one specify appropriate control measures and predict their performance? BRE, with some university and private sector laboratories, is conducting a major investigation into air leakage rates in dwellings, together with model studies. This should provide the first large scale experimental measure of infiltration rates, and hence of infiltration heat losses, in UK dwellings. I have already referred to some results from this investigation. BRE with BSRIA have also been developing techniques to investigate ventilation mechanisms in larger buildings. The Princes Risborough (timber) Laboratory of BRE has made detailed assessments of door and window draughtstripping products, the latter being funded by the EEO, and used these tests to develop suitable test procedures for incorporation in future British Standards. Figure 4 illustrates how some of the findings from these studies have been translated into simple advisory material aimed at the general public.

24. Thirdly, how can infiltration rates be conveniently measured and buildings checked for compliance with a mandatory level of

performance? BRE and the Polytechnic of Central London are investigating simplified tracer gas techniques, giving time-averaged rather than varying infiltration rates. The combination of a calibration rig for pressure testing and the publication of a protocol should lead to improved apparatus and techniques for pressure testing. An alternative design of measurement rig has been developed in a private sector laboratory with assistance from the EEO. Most university research into ventilation, funded by the Science and Engineering Research Council, has been in the general area of tracer gas techniques, and also in computer modelling studies. The British Gas Corporation has also had a programme of research in this general area.

25. Finally, occupants' reaction to the internal environment, and their response to different means of providing ventilation, has been studied in the past by the Electricity Council Research Centre and more recently through the BRE research programme (eg the study of window opening in office blocks published in 1984 - Reference 6) and through demonstrations and field trials in housing. Under the EEO's demonstration programme, trickle ventilators were installed at one housing estate with beneficial results while the Electricity Council have conducted field studies of mechanical ventilation in tightly-constructed houses with very positive reactions from occupants and more extensive trials are now in progress. These ventilation systems, equipped with heat recovery, provide an estimated 1/3ach at their normal setting and this appears to satisfy the occupants' needs. The cost of such systems - £1000 or more - is, though, high in relation to reduction in annual energy costs achieved.

Conclusions

26. In this address, I have attempted to show the contribution that proper control of infiltration can make to the improvement of energy efficiency in the UK, to consider the barriers to specifying infiltration rates in Regulations or in providing precise guidance on control measures, and to pick out the main features of research in progress in the UK relevant to these problems. I must now sum up and let you proceed to the papers which you have come to hear, and which will take this subject forward.

27. My aim has been to show that this is not a subject to be pursued primarily for its own sake, fascinating and complex though some of the aspects are. It is a deeply practical subject, with great relevance to the new problems that householders face in combating condensation and keeping warm at minimum cost and the legitimate concern of all building owners that their buildings should be weather-tight, economical to run and comfortable to live and work in. The aim of research should therefore be to advance knowledge in such a way that it can be of practical assistance to building owners and occupiers - accepting, of course, that research results have often to be 'translated' for building professionals and others through incorporation in Codes, advisory leaflets etc before they are accessible to their ultimate users.

28. Those engaged in air infiltration research should therefore be consciously working towards the development of low-risk construction practices which reduce infiltration in new buildings while maintaining

acceptable indoor air quality and avoiding condensation risks, or contributing towards the development and specification of acceptable means of modifying existing buildings, and the ability of regulators to specify and monitor ventilation requirements.

29. In considering the output from current research, and plans for future studies, therefore, certain questions come to mind:

Which problem area is this work addressing?

Who will use the results - and how can they be best presented for this purpose?

How much benefit will it bring through application?

30. The AIVC has, I believe, an important role here, not just in facilitating communication within the research community but in stimulating discussion of the means of presentation to the construction industry. Its recent change of title marks, I think, a recognition of this role. The Energy Efficiency Office stands ready to assist in getting research applied as, no doubt, do its counterparts in other countries. We want to make use of the best information available, to help us achieve the energy efficiency targets set for us. Your discussions here, and the other work of the AIVC, can help set us on the path to the £100 million or more savings to be achieved in this country through better control of infiltration, a sum which can be multiplied many times across IEA Members. As you listen to the presentations of the next three days, I hope you will always have that goal in mind.

31. Thank you for your invitation, and for your attention. May I offer my very best wishes for the success of this conference.

Acknowledgement

I am grateful to Dr H Danskin and Dr P R Warren of the Building Research Establishment for their assistance in the preparation of this address.

References

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2. Adapted from 'The Pattern of Energy Use in 1980' Energy Efficiency Paper No. 2, HMSO 1984

3. Warren, P R and Webb B C 'Ventilation Measurements in Housing' in CIBS Conference 'Natural Ventilation by Design', December 1980

4. BRE Digest 306 'Domestic draughtproofing: ventilation considerations' 1986

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6. Warren, P R and Parkins L M, 'Window-opening in office buildings' ASHRAE Transactions Vol 90, Part 1B 1984

TABLE 1

UK Energy Consumption 1984 by Sector

	Final Use	Primary energy
	%	%
Domestic	27.9	30.0
Commercial/institutional	13.0	15.8
Transport	27.8	22.0
Industry	31.3	32.2
	100.0	100.0
Total consumption	5682 PJ	8161 PJ

Sources: References 1 and 2

TABLE 2

Distribution of energy use in the domestic sector

(primary energy terms)

	%
Space heating	49
Water heating	21
Cooking	9
Lighting	4
Appliances	17

Source: Reference 2

TABLE 3

Distribution of energy use in commercial and institutional buildings

(primary energy terms)

	%
Space heating	47
Water heating	10
Cooking/catering	9
Lighting	23
Other uses	11

Source: Reference 2

TABLE 4

Annual space heating consumption for typical house

	1970		1980		1990	
	GJ	%	GJ	%	GJ	%
Fabric	46.9	75	35.5	71	17.4	60
Ventilation	15.6	25	14.5	29	11.6	40
TOTAL	62.5	100	50	100	29	100

Notes:

1. '1970': U=1.5 W/m^2K for walls, 0.8 for roof, 0.6 for floor
2. '1980': U=1.0 W/m^2K for walls, U=0.6 for roof and floor
3. '1990': U=0.3 W/m^2K for walls, roof, and floor (hypothetical)
4. Ventilation rate assumed to be 1.2 ach in all cases; the annual energy consumption consequent on ventilation losses falls as the heating season is reduced through increased insulation.

TABLE 5

Incidence of problems caused by damp/condensation in England

	%
No condensation/damp	51
Steamed windows	37
Deterioration of paint on sills	13
Mould or damage to decorations	15
Damage to floors, carpets, furniture	3

Source: Reference 5

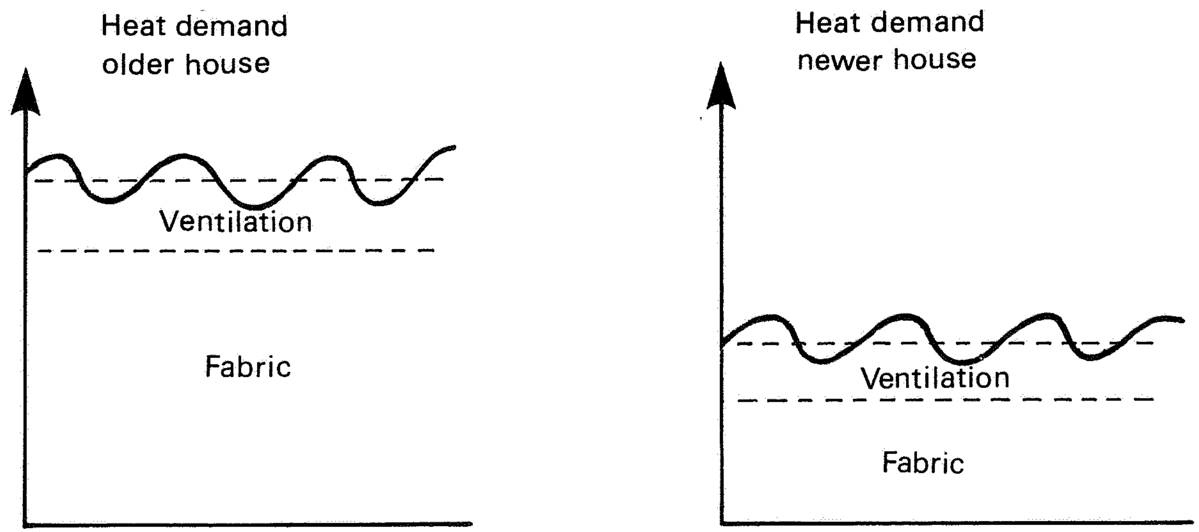


Figure 1 Variation in heat demand with wind strength and direction

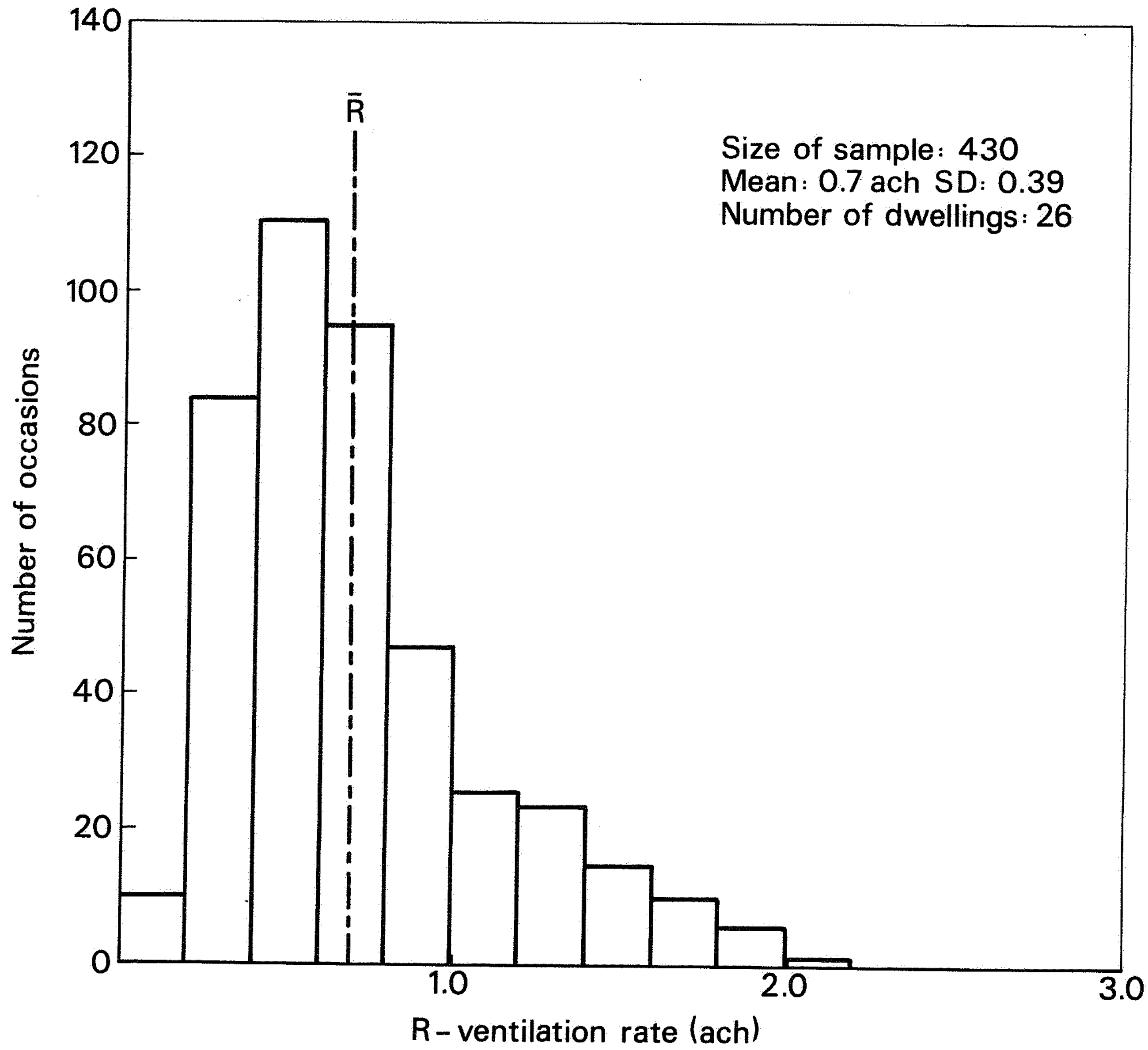


Figure 2 Distribution of whole house ventilation rates

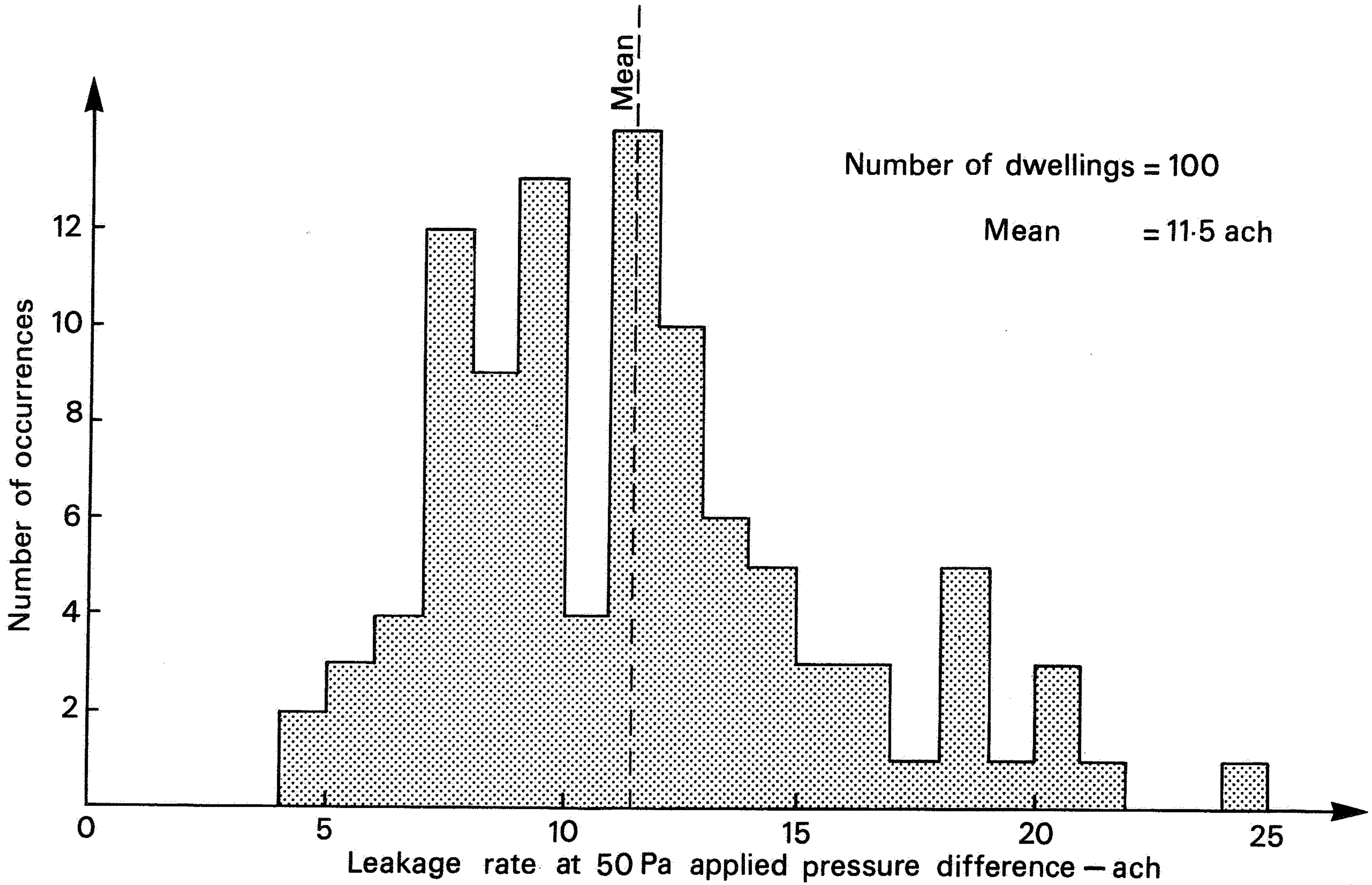
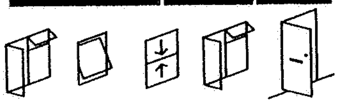


Figure 3 Distribution of whole house leakage rates at 50 Pa

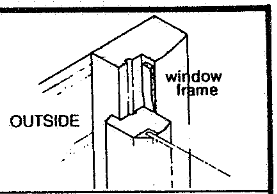
Which One is Best for My Windows and Doors?

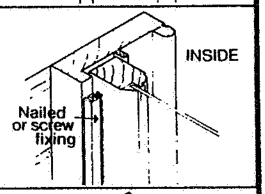
Look down the column and note which type of draughtstrip has the most stars for the type of windows and doors in your home.

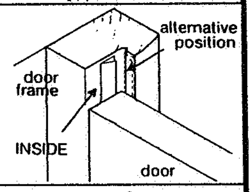
Look across, to find out the best material, how it is fixed, how much it costs and any other particular features. The third column shows how the draughtstrips are normally fitted. Look on the draughtstrip packaging for more detailed information.

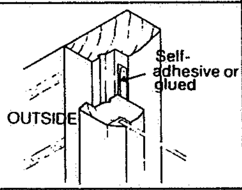


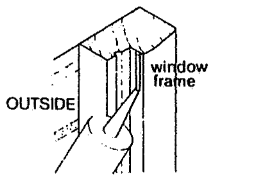
	Window: Wood			Window: Steel	Door	
Foams	* * *	* *	X	* * *	* *	**Best material** PVC foam with protective film. **Advantages** The quality of self adhesive strip has improved greatly. It is quick and easy to apply. Not visible when window is closed. Low cost. **Disadvantages** If used in small gaps, (under 2mm), needs a lot of force to compress. **Cost** 10 - 16p a metre for PVC foam, 30 - 65p a metre for EPDM rubber.
	(suitable only for gaps over 1.5mm wide)					
Brushes	* * *	Y	* * *	X	* *	**Best material** Soft nylon or polypropylene pile with central fin in a PVC or aluminium holder. **Advantages** Can be fixed to cope with a wide range of gap sizes. **Disadvantages** Brush piles should be removed when repainting. Visible when window or door is closed, but small PVC sections are unobstrusive. Fixing can be time-consuming. **Cost** 80p - £1.20 a metre. Self adhesive piles 30p - 50p a metre.
Thin sections	* *	* *	* *	* * *	* * *	**Best material** Flexible plastic **Advantages** Relatively cheap and easy to fix. Can cope with a wide range of gap sizes. **Disadvantages** The thin film may be prone to accidental damage, but can easily be replaced. When used as a wiper seal, it makes a 'crackly' noise when opening and closing, and may hum in high winds. **Cost** about 30 - 60p a metre for plastic V-strip.
Shaped sections	* * *	* * *	X	* * *	* *	**Best material** PVC or neoprene **Advantages** Very durable. Some are self-adhesive. **Disadvantages** Gluing sections in place with silicone sealant needs careful preparation, clean surfaces and some skill. Need to choose correct size of tubing relative to gap size. **Cost** about £1 - £2.50 a metre.
	(suitable only for gaps over 1.5mm wide)					
Sealants	* * *	* *	X	* * *	X	**Best material** Silicone rubber **Advantages** Very durable. Copes well with narrow and uneven gaps. **Disadvantages** Cannot cope with seasonal changes in gap size. Needs clean, well prepared surfaces and some skill to apply. Sealant needs to be left to cure before removing release tape and final trimming. **Cost** 60 - 80p per metre depending on gap size.











KEY X = unsuitable Y = may be suitable - depends on the design of the windows

* * * / * * / * The more stars the better the performance

Figure 4 Illustration of draught-proofing advice